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Carbon pricing and the food system: Implications for sustainability and equity

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ABSTRACT

Background: Climate change is a global problem, threatening the sustainability of the food system. Economic approaches like carbon pricing and emissions trading systems aim to put a price on carbon emissions to reduce greenhouse gas emissions. These initiatives have the potential to meet sustainability goals, but ensuring equity could be challenging. Additionally, the implementation and impact of these policies on the food supply system have not yet been fully understood and evaluated.

Scope and approach: As the food industry is a complex supply chain responsible for about 26% of global greenhouse gases, sudden implementation of these policies could disrupt the supply chain. Therefore, considering the perspectives of industries, distributors and consumers, it is important to carefully review the implications, efforts, and possibilities of these policies at different stages of the food supply system.

Key findings and conclusions: Adopting sustainable and environmentally friendly practices could minimize the impact of carbon policies and climate changes. Better incentives and household compensation can further lower the risk of food security. However, the social effects of the carbon pricing policy will be primarily determined by how revenues are recycled, how the policy is perceived and whether the carbon price signal is maintained.

1. Introduction

Carbon pricing (CP) is an economic approach to reducing greenhouse gas emissions by making them more expensive. It works by putting a price on carbon emissions through a carbon tax or cap-and-trade policy (emissions trading system (ETS)). When a price is put on carbon, it creates an incentive for emitters to reduce their emissions by switching to cleaner fuels, investing in energy efficiency measures, or reducing their output. Additionally, it can also be used to generate revenue, which can be used to fund renewable energy or research and development of low-carbon technologies. According to The World Bank (2023), there are 72 CP initiatives currently in force across the globe under national, and subnational jurisdictions (Fig. 1A). In 2023, these initiatives cover 11.66 GtCO2 emissions, representing 23% of global greenhouse gas emissions. According to the World Bank's annual "State and Trends of Carbon Pricing" report released on May 23, 2023, revenues from carbon taxes and ETS have reached a record high, approximately $ 95 billion (World Bank, 2023). However, the global economy has evident a number of challenges such as COVID-19 pandemic, war in Ukraine, and inflation, which are putting a strain on government budgets and making it difficult for some countries to afford to implement CP plans (Rabbi et al., 2023). In addition, the higher costs of fertilizer, seeds, and other agricultural inputs, together with carbon prices, could lead to shortages of certain foods and further increases in food prices (Brenton et al., 2022; Meena et al., 2023). This is a particular concern for developing countries, where food insecurity is already a major problem. As a result, political pressures from high energy prices could lead governments to deliberately lower carbon tax rates or postpone scheduled increases. It could be debatable that developing countries may not implement these policies immediately, as they may not be fair and equitable if not designed carefully (An et al., 2023; Green, 2021). This would undermine the effectiveness of CP as a tool to reduce greenhouse gas emissions.

The food industry has a complex supply chain, with emissions occurring at all stages of production, from farming to transportation to

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processing to packaging (Fig. 1B). The global food system can be divided into two categories: food production and non-food production, responsible for the global emissions of 52.3 billion tonnes of CO2 equivalents. While food production accounts for roughly 26% of global greenhouse gas emissions, non-food production contributes the remaining 74%. However, in a broader perspective, the supply chain, which includes food processing (4%), transportation (6%), packaging (5%), and retail (3%), contributes to a total of 18% of emissions. Livestock and fisheries, crop production, and land-use changes for agriculture each add significant portions, at 31%, 27%, and 24%, respectively. Food waste further complicates the issue, generating a staggering 3.3 billion tonnes of CO_2 equivalent emissions throughout the entire system. Therefore, it is important to address this sector to meet climate change goals (Ritchie, 2019).

One of the biggest challenges of CP is that CP could disproportionately impact low-income consumers (Feindt et al., 2021). Moreover, it can be challenging to measure and track the emissions of small-scale food manufacturers due to their less complex operations and less access to resources than larger manufacturers. However, making higher-emission foods (meat and dairy) more expensive to produce and consume can incentivize producers to switch to more sustainable farming and production practices and consumers to choose lower-emission foods (Kiss et al., 2019; Hassan et al., 2023; Adegbeye et al., 2020; Hassan et al., 2022). It is important to note that CP has the potential to achieve sustainability goals; however, ensuring equity could become challenging if policies are not designed and implemented carefully (Maestre-Andrés et al., 2019). A case study of CP in Canadian provinces shows that implementing CP has a deflationary effect on food prices, eliminating the misconception that CP increases inflation (Xu, 2024). The potential benefits of CP extend beyond immediate cost savings. By promoting food security and nutrition for all, CP can contribute to a more sustainable food system (von Braun, Afsana, Fresco, & Hassan, 2023). This approach considers economic, cultural, social, and environmental factors to ensure long-term food security and well-being for future generations. Succession planning, a crucial activity within any framework that implements CP, helps achieve these sustainability goals by ensuring continuity and knowledge transfer (Acheampong et al., 2023).

The agricultural sector has traditionally not been covered by CP schemes. However, New Zealand is set to become the first country in the world to price agricultural emissions by 2025 (Ardern et al., 2022). It will be interesting to see how the system will be implemented and its impact. Meanwhile, the food supply system must implement sustainable practices (Fig. 1C) to reduce the impact of carbon-based policies. By implementing these practices, the food supply chain can reduce its carbon footprint and become more resilient to the impacts of climate change. However, policies with better incentives in subsidies, innovations, and improved waste management could boost the adoption of these practices (Khan & Imran, 2023). The present review provides a comprehensive overview of the implications, efforts, and possibilities of these policies at different stages of the food supply system. It tries to explore how carbon pricing and emissions trading systems affect the sustainability of the food system. It also examines economic, environmental, and social aspects, including industry perspectives, policy effectiveness, and potential trade-offs between sustainability and equity. The goal is to understand how these policies can be designed for a balanced future. Therefore, a comprehensive overview of sustainability and equity helps to understand the challenges of farmers, food industries, and consumers. However, to keep the review focused, the role of sustainable agricultural practices is deemphasized, and the focus is solely on carbon-related policies. Additionally, while CiteScore was considered during the literature review, the primary focus was on identifying studies published in relevant journals and popular organizations within the past ten years, regardless of the specific CiteScore rank. This ensured a comprehensive review of recent research and reports on the topic.

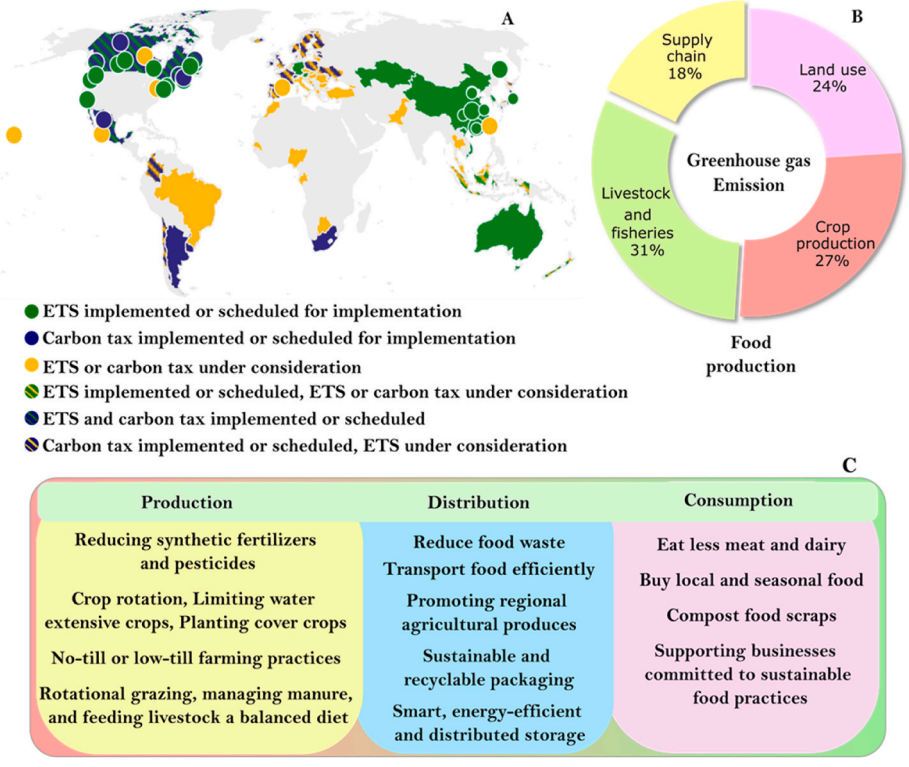
A
B
Supply chain 18%
Land use 24%
Greenhouse gas Emission
Livestock and fisheries 31%
Crop production 27%
Food production
ETS implemented or scheduled for implementation
Carbon tax implemented or scheduled for implementation
ETS or carbon tax under consideration
ETS implemented or scheduled, ETS or carbon tax under consideration
ETS and carbon tax implemented or scheduled
Carbon tax implemented or scheduled, ETS under consideration
C
Production
Distribution
Consumption
Reducing synthetic fertilizers and pesticides
Crop rotation, Limiting water extensive crops, Planting cover crops
No-till or low-till farming practices
Rotational grazing, managing manure, and feeding livestock a balanced diet
Reduce food waste
Transport food efficiently
Promoting regional agricultural produces
Sustainable and recyclable packaging
Smart, energy-efficient and distributed storage
Eat less meat and dairy
Buy local and seasonal food
Compost food scraps
Supporting businesses committed to sustainable food practices

Fig. 1. A. Global footprints of CP initiatives, **B.** Greenhouse emission of food production, and **C.** Sustainable practices to minimize the impact of climate changes and CP initiatives.

2. Sustainability and equity

Positive CP that incentivizes greenhouse gas (GHG) emission reductions is often counteracted by 'negative pricing' in the form of fossil fuel support, which incentivizes increases in GHG emissions. Fossil fuel support in the OECD and G20 countries has fluctuated since 2012, and support fell significantly in 2020 due to low fossil fuel demand and low prices from the early stages of the COVID-19 pandemic (OECD, 2019; OECD, 2022). Despite governments allocating one-third of funds to environmentally positive measures during COVID-19, fossil fuel support in 2021 (USD 697 billion) almost doubled compared to 2020 (USD 362 billion) (OECD, 2022). This sharp increase is likely due to the increase in energy prices as the global economy rebounded in 2021. Many countries have not yet fulfilled long-term commitments to phase out inefficient fossil fuel subsidies, in part because of efforts to protect vulnerable households from rising energy price impacts (OECD, 2022). During COVID-19, many countries also implemented CP policies encouraging increased emissions; however, most of these policies were time-limited (Nachtigall et al., 2022). Furthermore, in 71 countries, fossil fuel support was applied to approximately 22% of emissions (OECD, 2022). The vast sums of support allocated to fossil fuels are likely to disrupt the carbon price signal. Therefore, while current CP can reduce the dependency on fossil fuels of societies, it is unlikely that CP alone can initiate a transition towards net zero emissions (OECD, 2021; Rosenbloom et al., 2020).

Despite historically low average explicit carbon prices and coverage, explicit CP is estimated to have somewhat reduced emissions. However, there is little ex-post evidence of the impact of CP on emissions reductions (World Bank, 2022). A meta-review of 37 ex-post studies of CP since 1990 (mainly in Europe) found that CP schemes reduced GHG emissions in covered schemes by an average of 0–2% per year (Green, 2021). However, to keep the 1.5 °C temperature target within reach, annual average emission reductions of 7.6% globally between 2020-30 are needed (UNEP, 2019). However, Green (2021) points out that there is considerable variation between the results of different studies due to the use of different methods, different periods, and assessments of different sectors. Certain sectors show large emission reductions from CP.

CP may also have contributed to a lower average annual growth in CO_2 emissions in countries with established CP schemes applied at the national level. In a cross-country study, Best et al. (2020) found that the average annual growth of CO_2 emissions overall, and not just in sectors covered by CP, was 2% points lower in countries with established CP schemes applied at the national level than in countries without CP. The study also found that an increase in carbon prices of EUR 1/tCO2 was associated with emissions reductions of approximately 0.3 pp in the following year (Best et al., 2020).

Implementing CP within the food system can be effective in reducing emissions for several reasons. The price of carbon creates a financial incentive for food producers and consumers to reduce their carbon emissions. When carbon emissions have a cost associated with them, businesses and individuals are motivated to find ways to reduce emissions and lower their costs. Farmers, food producers, and supply chain participants may adopt more sustainable low carbon agriculture and production practices. This can include reducing the use of synthetic fertilizers, improving energy efficiency, implementing sustainable land management practices, and transitioning to renewable energy sources. CP can lead to increases in the price of carbon-intensive foods, such as those with high transportation or processing emissions. This can encourage consumers to choose lower carbon options, such as local and seasonal produce, reducing the carbon footprint of their diets. CP can incentivize farmers and food producers to engage in land management practices that sequester carbon, such as afforestation or agroforestry. This can contribute to carbon removal from the atmosphere. If implemented globally, CP in the food system can help reduce emissions in a sector that is an important contributor to global greenhouse gas emissions (Boyce, 2018).

CP can significantly promote sustainable food production practices by creating economic incentives for farmers and producers to reduce greenhouse gas emissions, decrease agricultural inputs, and improve soil health (Gramig & Widmar, 2018). CP assigns a price to carbon emissions in the form of cap-and-trade systems or carbon taxes. This incentivizes farmers and food producers to adopt practices that decrease their carbon footprint. They can implement more efficient energy use, switch to low carbon or renewable energy sources, and adopt conservation practices that reduce emissions from sources such as enteric fermentation in livestock (Shames, 2013). High-input agriculture practices often result in increased greenhouse gas emissions and environmental degradation. CP encourages farmers to adopt more sustainable and efficient farming methods. For instance, they may decrease the utilization of synthetic pesticides and fertilizers, which can release nitrous oxide and other harmful chemicals. Transitioning to organic, no-till, and agroecological approaches can help reduce input usage with associated carbon savings (Ansar et al., 2021).

Sustainable farming practices, for example, crop rotation, cover cropping, and reduced tillage, can enhance soil health. By sequestering more carbon in the soil and preventing erosion, these practices contribute to carbon storage and improved resilience to climate change. CP can incentivize farmers to implement these practices and invest in soil health. Reducing agricultural input and improving soil health often involves adopting agroecological practices that promote biodiversity. CP can indirectly support these practices by incentivizing the reduction of chemical inputs that can harm ecosystems. Diverse ecosystems can contribute to resilient and sustainable food production (Cox & Edwards, 2019).

Some CP mechanisms allow farmers to participate in carbon offset programs. These programs reward farmers for implementing practices that sequester carbon, such as reforestation, afforestation, and soil carbon sequestration. By creating a market for carbon offsets, CP can offer additional income to farmers adopting sustainable practices. Food producers and retailers downstream of the supply chain are also affected by CP. They may work with farmers and producers to reduce emissions and promote sustainable practices, knowing that CP will make high-emission products more expensive. This can lead to more comprehensive and coordinated sustainability efforts throughout the food production and distribution chain (Stringer et al., 2020).

CP can stimulate research and development in sustainable agricultural practices. Governments, businesses, and agricultural institutions can invest in technologies practices, human development, and equal work opportunities that reduce carbon emissions and enhance sustainability, creating a more fertile environment for innovation (Khan, 2023; Rosenbloom et al., 2020). Human development through technical knowledge and research can help a country shift towards clean, green technologies and efficient energy methods, ultimately reducing carbon emissions (Aqib & Zaman, 2023). Furthermore, research suggests a strong correlation between women's empowerment and environmental progress. A market-based study by Khan (2023) found that increasing female participation in the workforce positively impacts the environment and reduces carbon emissions. However, implementing CP can lead to potential trade-offs between sustainability and equity. One of the main equity concerns with CP is that it can disproportionately affect low-income and vulnerable populations. As the cost of carbon-intensive goods and services increases, these groups may face economic hardships. This can be seen as unfair and may exacerbate existing income inequality. Many mechanisms for pricing carbon, like cap-and-trade systems and carbon taxes, are regressive, meaning they place a larger burden on lower-income individuals and communities. This exacerbates economic inequality, since a higher percentage of the income of low-income households is spent on necessities such as energy and transportation, which often have few low-carbon alternatives (Boyce, 2018).

2.1. Equity

On a global scale, CP can have equity implications. Wealthier nations that historically contributed more to greenhouse gas emissions could implement CP policies more easily. However, poorer nations may struggle to do so. There is an equity argument for developed countries to provide technological and financial support to emerging countries to assist them in their transition to low-carbon economies. The way CP revenues are used can impact equity. If revenue is used to fund social programs or provide rebates to low-income households, it can mitigate some of the regressive aspects. However, if it is not distributed equitably, it may not benefit those who are most affected (Bauer et al., 2020).

To address these trade-offs and improve both sustainability and equity, policymakers can consider the following strategies.

- ***Progressive CP***: Implement a progressive CP structure considering household income levels. This can involve lower carbon taxes for necessities or essential transportation and higher taxes for luxury items or excessive energy consumption. A progressive structure can help reduce the regressive impact on low-income households (Cuevas et al., 2023).
- ***Revenue Recycling***: Use revenue generated from CP to support equity goals. For example, reinvest carbon tax revenues into social programs, clean energy projects, or public transportation systems. This can create jobs, reduce emissions, and directly benefit low-income communities (Scherer et al., 2018).
- ***Subsidies and rebates:*** Provide targeted subsidies and rebates to low-income households to offset the increased costs associated with CP. These measures can ensure that those most affected by the policy receive financial relief (Boyce, 2018).
- ***Community-Based Initiatives***: Support community-based initiatives in areas disproportionately impacted by CP, such as those with high-energy-intensive industries. Invest in economic diversification and retraining programs for workers affected by the transition away from carbon-intensive industries (Haug et al., 2018).
- ***Environmental Justice Assessments***: Conduct environmental justice assessments to analyze the effect of CP policies on marginalized communities. Use the findings to inform policy decisions and ensure vulnerable populations are not disproportionately burdened (Lockwood, 2017).
- ***Global cooperation***: Engage in international cooperation to address global equity concerns. High-income countries can provide financial assistance and technology transfer to low-income countries to support their transition to cleaner energy sources and adaptation to climate change (Bowen et al., 2017).
- ***Public Education and Engagement***: Invest in public education and engagement efforts to build support for CP policies. This can help reduce resistance and ensure that policies are sustainable over the long term (Scherer et al., 2018).
- ***Just Transition***: Implement a just transition framework that supports workers and communities affected by the shift away from carbon-intensive industries. Provide training and opportunities in green jobs to ensure a fair and sustainable transition (Cuevas et al., 2023).

Households are likely to be affected by a CP policy in two main ways (Fig. 2). The first way is through higher spending: When energy costs increase as a result of CP, so does the percentage of income that people spend on energy. Along with increasing the cost of fossil fuels such as coal, oil heating, and diesel, CP may also impact the cost of energy and industrial products and services (Kaufmann & Krause, 2016).

However, increasing expenses also motivate households to cut down on carbon-intensive consumption. Families must have outstanding options if they want to react to the price of carbon by switching to low-carbon substitutes. Few alternatives are available for certain goods and services, and some fundamental requirements must also be satisfied. Second, changes in income from wages (labor income), assets (capital income), and government transfers (social security, benefits) can all have an impact on family incomes (Kaufmann & Krause, 2016). The salaries (labor income) of employees at businesses that create carbon-intensive products and services, along with the returns on investments in the businesses, are all affected by CP. Because they rely on how firms respond to the carbon price, income impacts are less certain and more difficult to evaluate than spending effects. Generally, the more costs that can be passed to consumers, the less the carbon price will affect income and the more it will affect household expenditures. Emissions trading and carbon taxes can impact families similarly. However, how revenues are planned and used will significantly affect

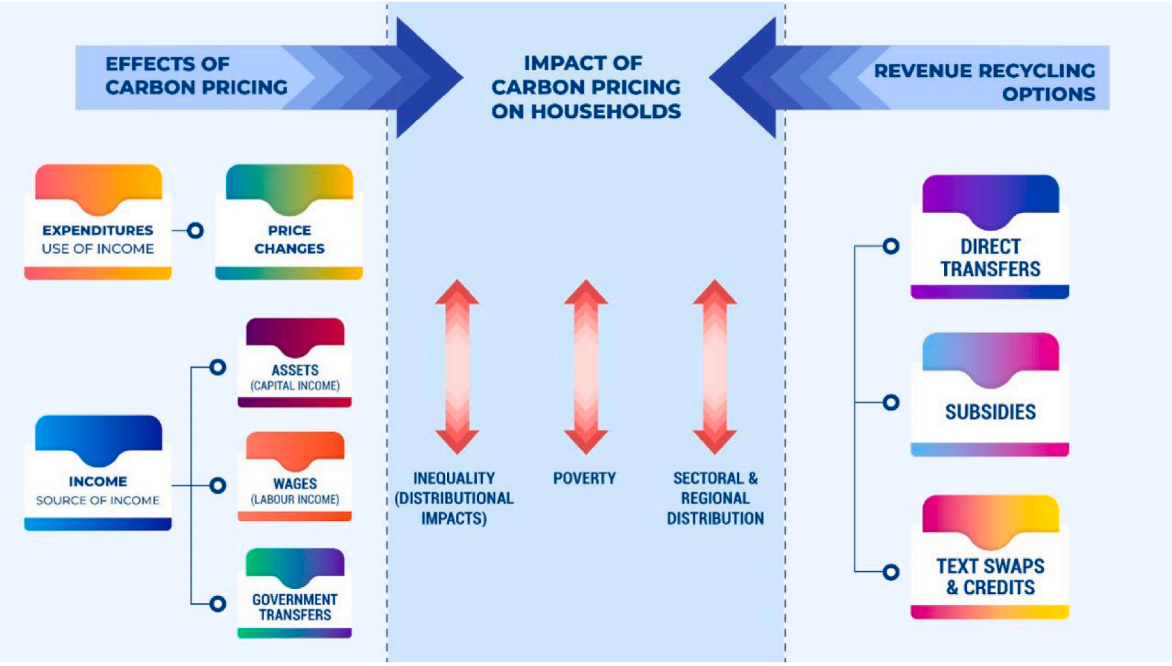

Fig. 2. CP impact on households and revenue recycling options.

how they are distributed in the end.

2.2. Distributional impacts of CP among households

Household distributional impacts of a carbon price are possible. When low-income families are hit proportionately harder than high-income households, a CP regime is deemed regressive. In general, the higher the intensity of carbon in a household's consumption, the larger the impact on expenditures (Kaufmann & Krause, 2016; Metcalf et al., 2011). Accordingly, families with high incomes often use more carbon-intensive products and services. As a result, they pay a higher absolute CO_2 price. However, when low-income families spend more of their income on energy- or carbon-intensive commodities, CP may affect them disproportionately.

According to Burtraw et al. (2009), most industrialized nations have shown that the carbon price is regressive. However, in developing and rising economies, CP is typically demonstrated to be progressive (Brenner et al., 2007). This is due to low-income families in emerging nations often spending small amounts on fossil fuels and products with a high carbon footprint, there are fewer cars on the road, and people use less fossil fuel for heating on average due to warmer weather (Krechowicz, 2011; PMR and World Bank Group, 2017).

2.3. Effects of CP on poverty

Regarding the distribution of income problem, CP can have an adverse effect on the most vulnerable people in society, thereby escalating the degree of poverty. Families in poverty have more difficulties than low-income households due to their fragility and limited ability to change their spending or income. Therefore, even small increases in the cost of necessities such as housing, electricity, food, and transportation may have a significant effect.

Energy poverty is crucial, since energy expenses are the most directly impacted by a carbon price (also called fuel poverty). In addition to energy availability, this includes "affordability challenges," mainly caused by low-income levels, high energy costs, and inefficient home energy consumption (Ürge-Vorsatz & Herrero, 2012). Energy poverty may be linked to access and cost in underdeveloped nations. In contrast, it is mainly linked to affordability in rich nations. Furthermore, energy-poor homes in developing nations may often utilize biomass energy, which is generally not covered by any carbon policy pricing and has environmental difficulties.

The primary goal of several national and international initiatives is to eliminate poverty. Policymakers should look for synergies and avoid conflicts when adopting CP measures, particularly when using funds to benefit low-income people. The Sustainable Development Goals' objectives for "Affordable & Clean Energy" provide a method for integrating CP into a larger framework for sustainable development.

2.4. Regional effects of CP

CP, also known as the spatial incidence of CP, can have a disproportionately negative impact on families in some places, just as it can have distributional effects across income categories (Pizer et al., 2010; Krause and Kaufman, 2016).

Current production and consumption patterns within particular communities, rural and urban areas, or geographic regions can cause disparities. The region's power production mix is one factor influencing regional variations in the effects of CP. Rising carbon costs affect areas that produce more power from fossil fuels more severely than those that use more renewable energy (Mehling & Tvinnereim, 2018).

Although this may fluctuate between industrialized and developing nations, residents in rural regions could be more impacted than those in metropolitan areas, since their energy expenditure (fuel and transportation) accounts for a larger percentage of overall income (PMR and World Bank Group, 2017). Lastly, communities whose employment and income depend on a particular sector that produces a lot of carbon may be particularly impacted by CP.

A policy of socially fair CP includes consideration of regional effects. Although there are several ways to provide compensation, some scholars think that using the carbon tax proceeds will probably be enough to solve regional differences (Kaufmann & Krause, 2016).

2.5. Options to mitigate the impact of CP on households

Utilizing the cash generated by CP offers the best chance of reducing the regressive consequences of carbon prices or enhancing their progressive advantages. When discussing "revenue neutral" CP, a course of action that reinvests all proceeds back into the economy, this is sometimes referred to as revenue recycling. There are three primary ways to utilize income from CP to address impacts: a) **direct transfers**, b) **subsidies**, and c) **tax swaps and credits.**

When using these alternatives, policy makers should take the following factors into account.

- *Aiding low-income families*: Some choices can efficiently disperse the cost of the program and reduce the burden on low-income households.
- *Maintaining the price incentives associated with CP*: The basic objective must be to provide the entire economy with a financial incentive to switch to low-carbon alternatives. Options should not obstruct this motivation.
- *Increasing the availability of low-carbon alternatives*: If consumers can alter their consumption and behavior, the price incentive will be more effective.
- *Increasing the effectiveness of the tax system*: Reducing taxes on other economic distortions may be done by utilizing revenue.

2.5.1. Direct (lump-sum) transfers

A direct transfer that returns CP money to families based on a per capita is an easy way to offset price increases brought on by the carbon price (Burtraw et al., 2009). Another name for this kind of direct assistance is lump-sum transfer, often known as "cap-and-dividend," "tax--and-dividend," or "sky trust." Households are compensated while the price of a carbon signal is maintained. Transferring the same "carbon dividend" to every home is the most straightforward method to construct it. Since poorer families benefit more from the carbon price proportionate to their income and/or expenses change, this is quite progressive (Burtraw et al., 2009; Williams et al., 2014).

Several jurisdictions have adopted this option. For example, as part of its cap-and-trade program, California legislated its promise to aid low-income families and vulnerable areas. Revenues through the cap-and-trade scheme are deposited into a Greenhouse Gas Reduction Fund (GGRF) under AB 32. The state has used a variety of techniques to defend low-income families and maintain the price signal at the same time. One of these measures is a climate credit or dividend, allowing people to receive auction proceeds on their power bills twice a year. These credits in 2015 ranged from $25 to $30 twice a year, depending on the number of customers served by the utility and the number of allowances provided (Gattaciecca et al., 2016). Climate credit is not affected by the CP signal since it is not related to power use. In California, low-income families are more likely to obtain credits than they do to pay for the increased power prices caused by the cap-and-trade scheme. The net financial effect of low-income households on their power bills was favorable; in 2016, they paid an average of $15 for electricity while receiving $65 in climate credits.

The dividend method is used in Switzerland, where all citizens pay a share of the income equally. The national health insurance program is used for this. Each household's stipend is applied to the cost of their premium health insurance (CPLC 2016).

2.5.2. Subsidies and other transfers

Consumption of certain items by families may be subsidized as a second alternative to offset the increase in CP. Public transportation, energy efficiency assistance, and food subsidies are available options. These subsidies may help the overall carbon price mechanism provide progressive results, depending on how they are constructed. Gonzalez (2012) examines the case of Mexico and finds progressive benefits when CO_2 tax income is recycled as a food subsidy, as opposed to regressive impacts when it is recycled as a decrease in manufacturing tax.

An alternative is to fund energy efficiency initiatives using the proceeds from CP. This is done, for instance, in California to lower the use of electricity, natural gas, and gasoline by state residents, lowering household energy consumption. Similarly, France funds the National Agency for Housing, which promotes energy efficiency improvements, using money from the EU ETS (CPLC 2016). Finally, government officials might use the proceeds from the carbon tax to raise welfare payments that are already progressive. The benefit of this is that it leverages existing institutional frameworks.

The results of the subsidy programs will vary by jurisdiction and the exact design and item that is subsidized. For instance, a public transportation subsidy that expands accessibility (such as adding subway lines) effectively gives families a low-carbon alternative and maintains the carbon price signal. However, subsidies could be created to inhibit the price signal. An example is a subsidy that immediately transfers income from CP to power prices. Customers would believe that power is less costly in this situation, shifting the price signal for CO_2, which could result in increased usage and emissions (Burtraw et al., 2012).

Long-term solutions to the problem of energy poverty are thought to be found in energy effective subsidies. Ürge-Vorsatz and Herrero (2012) compare three methods for reducing energy poverty (direct transfers to support the incomes of households, fuel subsidies to lower energy prices, and subsidizing energy efficiency measures) and claim that the policies promoting energy efficiency are the most effective at addressing both the change of climate mitigation along with the energy poverty.

2.5.3. Utilizing revenues to decrease other taxes (tax reform): tax swaps and credits

A "tax swap" is one kind of compensation that uses the proceeds from the carbon tax to permanently lower other types of taxation. It is possible to increase the effectiveness of the tax system by using money to lower already in place distorting levies like capital and labor taxes. In other words, the tax on a "good," in this instance, capital and labor, is replaced by a tax on a "bad," in this case emissions of CO_2. While an equal decrease in other taxes replaces the rise in carbon taxes, this alternative may help alleviate concerns about reduced competitiveness. However, the use of this approach has been discouraged by a number of writers since it may worsen the natural regressivity of carbon prices (Williams et al., 2014). A carbon-for-capital tax exchange initially benefits capital owners, often high-income people. Although a carbon-for-labor tax swap will be more equitable than a carbon-for-capital tax swap, even in that scenario, complete compensation for low-income families is not guaranteed. Last, a tax swap offers the advantage of maintaining the carbon price signal. However, this choice does not increase the chances of switching to cleaner alternatives for carbon-heavy products and services (Table 1).

Introducing a tax credit is a more focused solution to assist low-income people. Tax credits help people and businesses pay less in taxes to the government. A tax credit, instead of a tax swap, may be directed toward low-income families based on qualifying requirements and can be personal or per family. Low-income families in British Columbia are given a tax credit for climate action due four times a year to offset the effects of the carbon price. In British Columbia, the level of credit is based on the size of the family and its adjusted net income (British Columbia, 2017). Carbon tax credits may or may not be progressive, depending on how they are set up. For instance, Callan et al. (2008) found that tax credits would be progressive, but tax swaps would be regressive in their analysis of Ireland.

Table 1
CP impacts on households and design options for revenue recycling (Williams et al., 2014).

Households	Direct (lump sum transfers)	Subsidies	Tax Reform: Credits and savings
Supports low-income households	Yes	Partially	Potentially
Preserves the carbon price Incentives	Yes	Partially	Yes
Increase the availability of low-carbon substitutes	No (may have lock-in effects)	Potentially	No
Reduces distortionary taxes	No	No	Yes

Both tax swaps and credit-based strategies were utilized in the real world. For instance, with the aforementioned environment tax credit, British Columbia also applied personal and corporate income tax reductions with its carbon tax to make it revenue neutral. According to early studies of those programs, British Columbia's policies were regressive in and of themselves. However, there was an overall improvement since money was recycled via the tax swap and low-income tax credit (Beck et al., 2015). The tax system was anticipated to benefit the poorest 40% of families in its first year of operation, 2008–2009.

2.6. An overview of household compensation alternatives

The social effects of the CP policy will be determined mainly by how the funds are recycled. However, it will also affect how the policy is seen and whether or not the CO_2 price signal is maintained. The key factors that policymakers should take into account when deciding which possibilities to provide families compensation are: i) their ability to maintain the signal from the price of carbon, ii) to maintain or enhance social equality, iii) to address issues about competition, iv) to expand the range of low-carbon choices, and v) to lower other tax distortions. Direct lump sum compensation would have been progressive but not as beneficial to the tax system as tax swaps, as indicated in Table 1 (Williams et al., 2014). The item and design of the subsidy will determine the distributional result, but the effectiveness of the tax system is unaffected.

The selection of support would also affect the reliability of the pricing signal and the accessibility of cleaner alternatives. For example, the carbon price signal may be preserved using any of the three approaches. However, particular consideration should be given to how the ETS and certain types of subsidies interact. To get more support for CP programs, efforts must be made to clearly express the support measures. Some kinds of payment are more pronounced, including dividends shown on home power bills. Other initiatives, including incentives for energy efficiency, are not explicitly labeled as compensation. The program's lifespan is strengthened by openly disclosing the proceeds and uses of the carbon price. One way CP can promote equity in the food system is by using the revenue generated from these carbon taxes to support low-income consumers. By implementing policies that redistribute the funds collected from CP, governments can provide financial assistance to individuals and families disproportionately impacted by the rising food costs due to CP. This can help mitigate adverse economic impacts on vulnerable populations and ensure affordable access to nutritious and sustainable food. For example, a short food supply chain helps to ensure sustainability, financial resilience, and social well-being in the food system (Soria-Lopez et al., 2023).

Furthermore, the revenue generated from CP can also be directed towards funding sustainable food production projects. These projects can include initiatives that support local and regenerative agriculture, reduce food waste, and promote sustainable farming practices. By investing in such projects, CP can not only mitigate the negative

environmental impacts of the food system but also create opportunities for small-scale farmers and communities to transition toward more sustainable and environmentally friendly food production methods. This, in turn, can contribute to long-term food security and resilience.

One approach is to use the revenue to support low-income consumers. Many low-income individuals and families struggle to afford nutritious food. CP revenue can be redistributed to these vulnerable populations through subsidies, vouchers, or direct financial assistance, which can help alleviate the burden of rising food costs. This promotes equity by ensuring that everyone has access to healthy food and mitigates the regressive nature of CP, which could disproportionately affect lower-income households (William et al., 2014).

CP not only benefits the climate, but can also produce positive local environmental and social outcomes, known as co-benefits, for instance, in terms of improved public health from reduced emissions of air pollutants. CP creates a financial incentive for businesses and individuals to reduce carbon emissions. In the food system, this can decrease emissions associated with agriculture, transportation, and food processing. The sustainability measures encouraged by CP, such as diversifying crops and reducing dependence on fossil fuels, can make the food system more resilient to the impacts of climate change. CP can help ensure the long-term viability of the food system by mitigating the impacts of climate change and resource scarcity (Fig. 3).

3. Current CP policies

CP policies for the food sector, industries, and consumers include strategies to address carbon emissions. For the food sector, policies like carbon taxes and emissions reduction targets incentivize sustainable agricultural practices and reduce emissions associated with production and transportation (Kruger et al., 2007). On the other hand, industries are affected by mechanisms like the cap-and-trade system, encouraging emission reductions through tradeable allowances (Stavins, 2008). Additionally, industries may benefit from revenue returned to citizens through dividends or tax cuts, mitigating economic impacts (Rausch et al., 2010). Consumers may experience price changes due to CP. However, they can also benefit from the increased availability of sustainable products and potential dividends from revenue neutral policies (Klenert et al., 2017). This multifaceted approach aims to drive emissions reductions across the entire supply chain, from production to consumption.

3.1. Farmers

Agriculture policies play a pivotal role in shaping farmers' livelihoods, the sustainability of industries, and food affordability for consumers. It is imperative to periodically review these policies to assess their effectiveness and identify areas that need change to mitigate negative impacts. CP policies can influence agriculture by incentivizing emission reduction, promoting sustainability, and driving innovation. Although they can increase the costs of traditional framing practices, they can also create opportunities for farmers to adapt, invest in more sustainable methods, and participate in emerging carbon offsets and clean energy production markets. Effective policy design and ongoing support are essential to ensure a just transition for the agricultural sector while addressing climate change concerns. These policies can have positive and negative impacts on farmers, depending on various factors such as the design of the police, the agricultural practices involved, and regional variation.

3.1.1. Positive impacts on farmers

Incentives for sustainable practices: CP can incentivize farmers to adopt more sustainable and environmentally friendly practices, such as reduced tillage, cover cropping, and agroforestry. These practices can improve soil health and reduce emissions (Lal, 2021).

Diversification and Income: Some CPPs can encourage the diversification of crops or livestock, which can spread risks and provide alternative income streams. For example, carbon markets can reward farmers for adopting reforestation and afforestation projects (Shukla et al., 2019).

Access to the carbon market: Farmers can benefit financially by participating in carbon offset markets, generating income by sequestering carbon through practices such as afforestation, reforestation, or soil carbon sequestration (Niles et al., 2002).

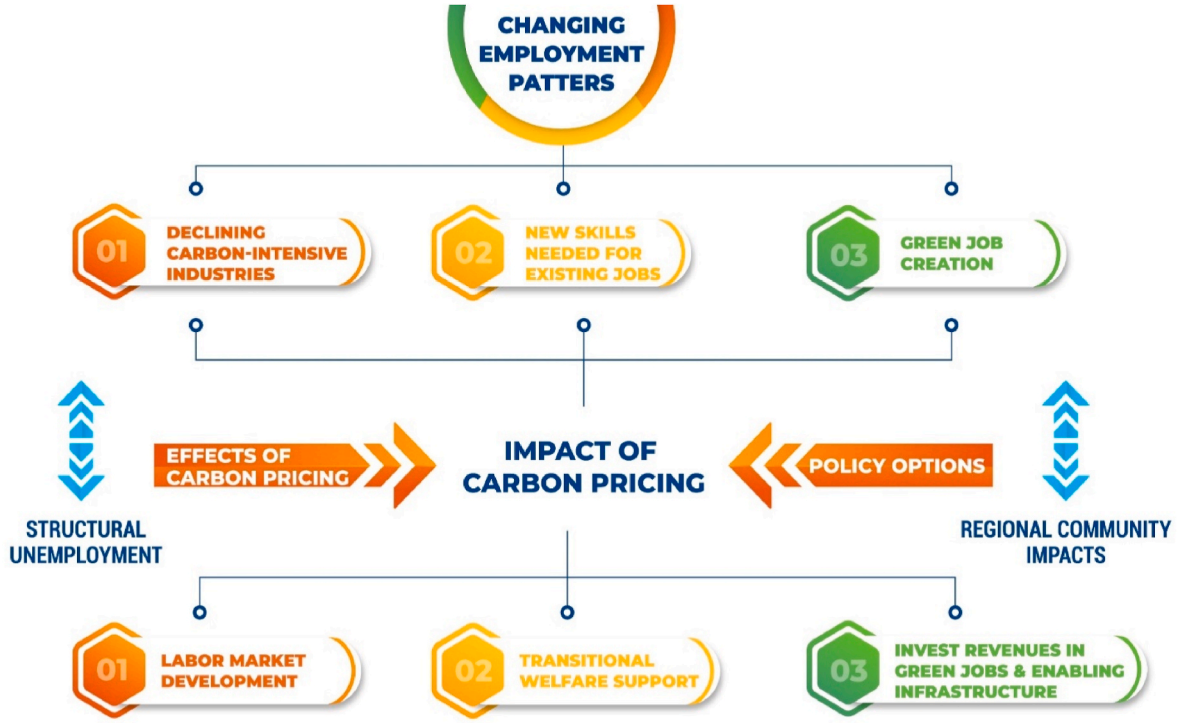

Fig. 3. Co-benefits distribution and CP.

Research and innovation opportunities: CP can stimulate research and innovation in agriculture. Farmers may seek more efficient practices and technologies to reduce emissions, improving yields and profitability.

3.1.2. Negative impacts on farmers

Increased costs: Some CP policies, such as carbon taxes or cap and trade systems, can increase farmers' energy and input costs. This can impact their profitability, especially if they cannot pass this cost on to consumers.

Competitiveness: Farmers may face challenges competing with producers in regions with stringent CPPs than those in areas with laxer regulations. This can lead to economic disparities and impact the viability of the agricultural sector in certain regions (Baylis, Fullerton, & Karney, 2014).

Land use change restrictions: Some CP policies can limit land use changes, which can affect farmers' ability to convert land for agricultural purposes. This is particularly relevant in regions with high conservation requirements (Le Polain de Waroux et al., 2021).

Implementation challenges: CP can introduce complexities and challenges in implementation and compliance, which may disproportionately affect smaller, less-resourced farmers (Stavins, 2019).

3.2. Food industries

CP policies significantly impact various industries, including the food industry, as they are designed to internalize the cost of greenhouse gas emissions and promote the transition to a more sustainable low-carbon economy. In food systems, designing and implementing policies such as GHG emission verification is essential for quantifying emissions and identifying hotspots. Several international standards, such as GHG protocols, ISO 14064, ISO 14067, PAS 2050; PAS 2060 help measure and report GHG. These global standards provide three scopes (emissions from: 1- manufacturing process, 2- energy outsourced, 3- pre- and post-processing) to understand and identify different direct and indirect sources of GHG throughout the entire food chain supply (Liu et al., 2023). In the food industry, the following strategy could be utilized to mitigate GHG emission.

Enhanced energy efficiency in processing- Effective energy management by reducing power consumption, adjusting production schedules, improving equipment schedules, and implementing continuous processing methods.

Adopting emerging technologies: Innovative and emerging technologies such as high-pressure processing, ohmic heating, pulse electric field, and microwave heating have shown great potential in the food processing sector by providing efficacy and reducing energy consumption.

Energy decarbonization: Explorations of innovative and clean energy resources and energy-efficient transportation systems to achieve energy decarbonization. In recent years, many international food manufacturing industries such as Nestlé and European Clean Trucking Alliance call for more sustainable road freight (2020, July 15), Cargill (2023), and Pepsico (2024) have implemented on-site renewable energy solutions and clean energy mediums for transportation to achieve energy decarbonization.

Effective logistics strategies: Logistics strategies such as short supply chain focus on localized production, which reduces the distance from the farm to the production and for consumption sites and helps reduce GHG emission.

Carbon dioxide utilization during food processing: In food manufacturing industries, CO_2 is used in various forms such as a chilling agent, dry ice, low-pressure chilled liquid, and high-pressure cylinder gas. Capturing and using CO_2 for other food processing products helps create new valuable products. For example, beverage manufacturing companies require 70% of all food-grade CO_2. CO_2 captured from alcoholic fermentation could be used by these companies to meet their CO_2 requirements.

Food packaging: The materials used for food packaging and their weight contribute significantly to GHG emissions. Plastic-based materials produce 3 kg CO_2 eq/kg, whereas cellulosic fiber-based materials produce half that amount. However, cellulosic fiber-based packaging requires more material to provide a similar degree of protection. Therefore, better-optimized designs and the use of recycled food packaging materials could reduce the environmental impact.

Alternative food sources: Apart from elimination strategies in food manufacturing, the food processing and manufacturing industries could focus on products that have a lower carbon footprint. For instance, plant-based foods result in reduced GHG emissions compared to animal-derived foods. Cultured meat technology is another alternative that produces meat using cell culture in a bioreactor, eliminating the need for livestock systems. Another promising option is the exploration of microbial protein foods from fungi, yeast, and bacteria, which minimizes the need for extensive land use.

3.2.1. Positive impact on food industries

Incentives for emission reduction: CP policies incentivize industries to reduce carbon emissions. Companies that can find ways to reduce their emissions more cost-effectively than paying for allowances or taxes can gain a competitive advantage. This can drive innovation in clean technologies and more efficient production processes.

Investment in carbon offset: Some industries may invest in carbon offset projects, such as reforestation or renewable energy initiatives, to balance emissions. This can create new opportunities for companies specializing in carbon offset projects.

Reducing climate risk: By reducing carbon emissions, these policies contribute to global efforts to mitigate climate change, which can ultimately reduce the risks of extreme weather events and their impact on industries.

Market signals for green products: CP encourages the development of green products and services, as there is an increasing demand for low-carbon alternatives. Industries that offer sustainability can benefit from a growing market.

3.2.2. Negative impacts on food industries

Transition challenges: Industries with high emissions and long investment cycles, such as fossil fuels and heavy manufacturing, may face significant challenges in the transition to low-carbon operations. These industries may require financial support or transition plans to adapt to the new regulatory environment.

Competitiveness concerns: Industries in regions with strong CP policies may face competitive disadvantages. This could lead to a risk of 'carbon leakage' as some businesses relocate to regions with laxer regulations (Gorry et al., 2017).

Social equity: CP can result in higher energy costs, which may disproportionately affect low-income households. It is important to design policies with measures to protect vulnerable populations and address social equity concerns (Calel & Dechezleprêtre, 2016).

Complexity and administrative burden: Implementing and managing CP policies can be administratively complex. This can be a burden, especially for small businesses. Careful design and administrative measures are needed to minimize compliance costs (Murray & Rivers, 2015).

3.2.3. Challenges associated with the transportation of perishable food commodities

According to (FAO, 2023), one third of global food production losses occurred due to food waste. Furthermore, 1.3 billion food waste losses occur due to deficiencies and limitations in our current food chain supply system. In 2011, 492 million fruits and vegetables were wasted due to a poor supply chain system (Gardas et al., 2018). Therefore, the supply chains of perishable food products have been associated with a number of challenges and concerns. These include inadequate consideration of product attributes and perishability dynamics in supply chain,

ineffective logistics coordination, insufficient preharvest care, and ineffective demand management. These results in spoilage and generation of waste that ultimately decompose to produce GHG. In addition, the energy used to grow, harvest and transport spoiled food is wasted, contributing to the overall carbon footprint of the food system. Unfortunately, quantifying the emissions associated with food spoilage during transport is complex, making it challenging to incorporate these costs into carbon pricing schemes. If carbon pricing increases transportation costs for perishable goods, it can disproportionately impact producers and consumers, potentially leading to resistance to such policies. Therefore, investing in better cold storage facilities and efficient transportation networks can reduce spoilage and optimize routes. Smarter refrigeration systems, better insulation, and real-time monitoring can improve efficiency and reduce energy use.

3.2.4. Challenges associated with food packaging

Although food packaging has a small carbon footprint for food companies, it remains a major concern for consumers, politicians, and NGOs, creating a challenge for the industry (Burrows, 2022). It is facing several challenges at various levels. Environmentally, there is a struggle with inadequate application of circular economy principles, a negative impact on biodiversity, nonrecyclable materials, poor packaging performance, and inadequate reverse logistics, which pose risks to human consumption. Economically and socially, the issues include the high cost of virgin materials, limited financial resources, uncertain returns on investment, lack of awareness, misperceptions, and resistance to change. Within the supply chain, there are deficiencies in innovative packaging, challenges in validating and testing new designs, and lack of transparency in data. There are also governmental challenges, including outdated compliance requirements and inconsistent regulations and tax incentives.

3.2.5. Other concerns and challenges

The CP market encourages the food industry to adopt measures to reduce GHG emissions, potentially transforming the food system to address climate change. However, if the cost of implementing these measures exceeds carbon taxes, manufacturers may opt to pay the taxes instead. To prevent this, policies should avoid imposing financial restrictions on smaller companies. In addition, standardizing GHG emission verification is challenging due to inadequate emission reporting and data. These issues pose significant barriers to reducing the carbon footprint. Despite these challenges, CP can potentially drive transformative changes in competitiveness, innovation, and investment decisions. Although CP may initially pose challenges for some industries, it creates opportunities for those who are forward-thinking and willing to invest in cleaner, more sustainable technologies and practices. As countries and regions continue to adopt CP policies, businesses and investors are increasingly factoring this consideration into their strategic planning and decision-making processes.

3.3. Consumers

CP policies, such as carbon taxes and cap–and–trade systems, aim to address climate change by putting a price on carbon emissions. Currently, at the consumer level, no emissions pricing schemes are applied. However, in some countries, food related taxes are introduced to minimize the negative health impact. For example, Mexico applied the sugar-sweetened beverages tax and reduces the 5% consumer to non-consumer in three years and South Africa applied 10% health promotion leavy in most popular soft drinks (Carriedo et al., 2021; Abdool Karim, Kruger, & Hofman, 2020). Similarly, in Denmark, the tax on saturated fats was applied and reduced the intake by 4% in 13 months before its removal (Smed et al., 2016). These potential impacts help to mitigate GHG in the medium stage of consumption. In addition, the Republic of Korea used volume-based food waste fees from household waste generation and in some EU countries general household waste taxes included food waste (Kim, 2022). These potential impacts help to mitigate low GHG mitigations; however, the technical implementation issue still remains. Therefore, these policies can have both positive and negative impacts on consumers.

3.3.1. Positive impacts on consumers

Change in consumer choices: CP encourages individuals and businesses to reduce their carbon footprint by making energy-efficient choices by choosing technologies and practices that can lead to lower energy bills and savings over time.

Revenue redistribution: Some pricing systems return revenue to consumers through dividends or tax cuts. This can help offset the increased costs associated with CP and ensure that lower-income individuals do not bear a disproportionate burden (Burger et al., 2020).

Promotion of clean energy sources: The CPP can stimulate investments in renewable energy sources. As the demand for clean energy increases, the cost of renewable technologies can decrease, benefiting consumers in the form of cheaper and cleaner energy options (IEA, 2020).

Revenue recycling: Some CP programs use revenue generated from carbon taxes or emissions allowances to fund projects that benefit consumers, such as public transportation, energy-efficient infrastructure, or even direct rebates to households (Carattini & Tavoni, 2016).

3.3.2. Negative impacts on consumers

Higher energy costs: CP policies can increase energy costs, particularly for industries with high emissions. These increased costs can be passed on to consumers through higher electricity and fuel prices ET (Macaluso et al., 2018).

Regressive impact: In some cases, CP can have regressive effects, burdening lower-income households more. This occurs when energy costs make up a larger share of the budget for low-income individuals, and the policy does not include adequate measures to address this issue (Burtraw et al., 2015).

Economic transition challenges: Industries that are highly dependent on carbon-intensive processes may face economic challenges as they adapt to the new carbon-constrained environment. This can lead to job displacement and economic disruption in certain regions, negatively impacting consumers living in those areas (Rausch et al., 2019).

Risk of leakage: In a global context, CP can lead to "carbon leakage" where emission-intensive industries move to regions without CP to avoid costs. This can result in a transfer of emissions rather than an overall reduction, which may not be effective in addressing the global climate issue (Branger et al., 2016).

Addressing the regressive effects of CP requires a comprehensive and multipronged approach tailored to the specific needs and circumstances of different communities. When designing these policy adjustments, it is important to consider the broader context of a country's social safety nets and economic conditions. The goal should be to mitigate carbon emissions and promote social equity, ensuring that the burden of transition to a more sustainable economy is shared equitably, with particular attention to those most vulnerable in society.

4. Future guidelines and conclusions

In the future, CP policies should be designed to address the unique needs and challenges facing farmers, consumers, and industries. For farmers, the guidelines should emphasize incentives for sustainable agriculture, including carbon sequestration practices and access to renewable energy sources. Consumers should be protected from excessive cost burdens through targeted support and compensation mechanisms. At the same time, industries should receive clear emission reduction targets, innovation incentives, and international collaboration to maintain competitiveness. Overall, future CP policies should be characterized by a balance between environmental sustainability and economic growth, with a strong focus on social equity and adaptability

to evolving circumstances.

In conclusion, CP has emerged as an effective economic tool for reducing greenhouse gas emissions and promoting sustainability in various sectors. However, as governments face financial challenges and the potential for increased food prices, there are concerns about the equity and fairness of implementing CP policies, especially in developing countries. It is crucial to carefully design and implement these policies to ensure that they do not disproportionately burden low-income consumers or hinder the accessibility of essential food items. However, by making high-emission foods more expensive and incentivizing sustainable farming and production practices, CP can play a significant role in achieving climate change goals and reducing the carbon footprint of the food industry. To effectively address the impact of carbon-based policies on the food system, it is important to integrate sustainability practices throughout the supply chain, from farming to transportation to packaging. A possible solution involves identifying key gaps before or after harvesting. This includes the development of packing houses, information exchange centers for farmers, processing facilities near supply chain locations, storage facilities for surplus production, investment in rural infrastructure and better management and accountability of the cold supply chain for perishable food commodities. For packaging materials, the principles of a circular economy must be implemented to maintain a balance between environmental safety and the reduction of carbon footprints. Adopting these can not only reduce carbon emissions, but also enhance resilience to the challenges posed by climate change. However, it is crucial for policy makers to provide appropriate incentives and support, such as subsidies, innovations and improved waste management, to promote the widespread adoption of sustainable practices.

CRediT authorship contribution statement

Mehvish Habib, Sakshi Singh, Yograj Bist: Writing – original draft, Investigation, Visualization. Yogesh Kumar: Writing – original draft, Writing – review & editing, Methodology, Conceptualization. Kulsum Jan, Khalid Bashir, Shumaila Jan, D C Saxena: Writing – review & editing, Conceptualization, Validation, Supervision.

Declaration of competing interest

The authors declare no conflict of interest.

Data availability

Data will be made available on request.

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